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Embodied Carbon In the U.S. Manufacturing and Trade

Ali Hasanbeigi, Ph.D.
Global Efficiency Intelligence

William R. Morrow, Ph.D. and Arman Shehabi, Ph.D.
Lawrence Berkeley National Laboratory

Global Efficiency Intelligence

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Executive Summary

On average, one quarter of the global carbon footprint is embodied in traded goods. These emissions are a growing issue for global efforts to decarbonize the world economy. Embodied emissions in trade are not accounted for by existing greenhouse gas accounting systems. For example, countries only report their domestic carbon emissions (also known as production-based or territorial accounting) to the Intergovernmental Panel on Climate Change (IPCC). If the embodied carbon in trade were accounted for and reported, the promising climate trends depicted by many countries would be negated or reversed. For example, many achievements of reducing emissions by developed countries under the Kyoto Protocol would actually appear as emissions outsourced to developing countries.

Like many other developed countries, the United States is a net importer of embodied greenhouse gas (GHG) emissions in trade. The goal of this study was to calculate the carbon footprint of various sectors of the U.S. economy using the latest available data and based on that, estimate the embodied carbon in certain manufacturing sector products imported and exported by the U.S.

First, we conducted an input-output analysis to calculate the carbon footprint of 401 aggregate level sectors of the U.S. economy. After that, for a selected number of manufacturing subsectors /products(hereafter referred to as products),we collected their trade(import/export) data and combined that with their computed carbon footprint to estimate the embodied carbon in import and export of these products for the U.S. While we conducted the carbon footprint analysis for sectors covering the entire U.S. economy (401 sectors), we only conducted the embodied carbon in trade analysis for a few products within specific aggregate level manufacturing sectors,such as computer and electronic product manufacturing (NAICS 334), transport equipment manufacturing (NAICS 336), machinery manufacturing (NAICS 333), and chemical manufacturing (NAICS 325). It is possible to do the detailed embodied carbon analysis for all other products within the various aggregate level manufacturing sectors of the U.S. economy, but given the scope of this study and space constraint of this report, we only present the results for a few products.

The results of our analysis for the selected products show the embodied carbon in trade for each product by country and also show the rankings of countries in terms of top importers and exporters of embodied carbon in trade with the U.S. Our results show that in majority of cases, the U.S. is a net importer of embodied carbon in trade.

Unless consumption-based accounting is used, the U.S. and other net embodied carbon importing countries may continue to outsource their emissions to meet their climate change mitigation targets under the Paris Agreement, as observed previously with the Kyoto Protocol. Some countries reported reductions that exceeded their Kyoto targets, however, the changes in emissions embodied in imports were comparable to or larger than changes in domestic emissions. Traded emissions undermined emissions reductions in the Kyoto Protocol, and threaten to continue to do so for the Paris Agreement. New climate policies such as California's Buy Clean act, EU's proposed border carbon tax adjustment, as well as efforts in the private sector can help address the embodied carbon in traded products.

Table of Contents

1 Introduction

The globalized trade system entails substantial flows of goods and services from countries of production and provision to different countries of consumption. In many cases, and increasingly so, the majority of production and provision is occurring in developing countries, with developed countries acting as importers and net consumers.

Under the United Nations Framework Convention on Climate Change (UNFCCC), countries report their greenhouse gas (GHG) emissions on the basis of territorial emissions (also called production-based accounting (PBA)). When goods are traded, the emissions associated with their production (or embodied emissions) are also traded, and these emissions linked with imported goods do not get counted towards the consumer country's emissions account. Many argue that the existing accounting methodology should be amended to reflect emissions embodied in imported goods, paving the way for consumption-based accounting (CBA). The term 'embodied emissions' refers to the total amount of emissions from all upstream processes required to deliver a certain product or service. These embodied flows of carbon, which are not accounted for in PBA, are called embodied emissions, emission transfers, or displacement.

More local and national governments are trying to address the issue of carbon embodied in trade. For example, the new Buy Clean Act in California (AB 262) requires that certain carbon-intensive infrastructure materials (including steel and glass) purchased with state funds adhere to specific guidelines regarding carbon intensity thresholds. The Buy Clean legislation helps expand the market for companies that have invested in low-carbon technologies for producing materials.

Recent studies have shown that, the utilization of consumption-based accounting results in the negation or reversal of the apparent progress made by developed countries towards reducing their emissions, due to import of embodied emissions from developing countries. Accordingly, much of the increase in emissions in developing countries can be attributed to production for export to developed countries. It is estimated that 25% of global CO_2 emissions are embodied in traded products, that is, these emissions are associated with goods and services that are internationally traded. Better understanding of embodied emissions and accounting methods is critical for informing future discussions on decarbonizing world economies. Consumption-based accounting allows developed countries to take responsibility for upstream emissions that could otherwise be ignored. However, data and research in this area are still emerging, and have only analyzed the embodied carbon in trade at a relatively low-resolution in terms of countries and sectors. A detailed, up-to-date global quantification that can inform policy is needed.

This study aims to use the latest available data to quantify the carbon footprint of over 400 aggregate level sectors of the U.S. economy. In addition, the study aims to estimate the embodied carbon in manufacturing sector products traded in the U.S. The results of our analysis for a selected few products are presented in this report. We also discuss the current state of private and public sector usage of embodied carbon emissions accounting. Finally, the report summarizes our conclusions and implications for future climate policy.

2

High-level View of Embodied Carbon In Global and U.S. Trade

On average, one quarter of the global carbon footprint is embodied in traded goods (Hasanbeigi et al. 2018; Peters et al., 2011, Andrew et al. 2013). These hidden flows evade most types of carbon policy (Figure1).

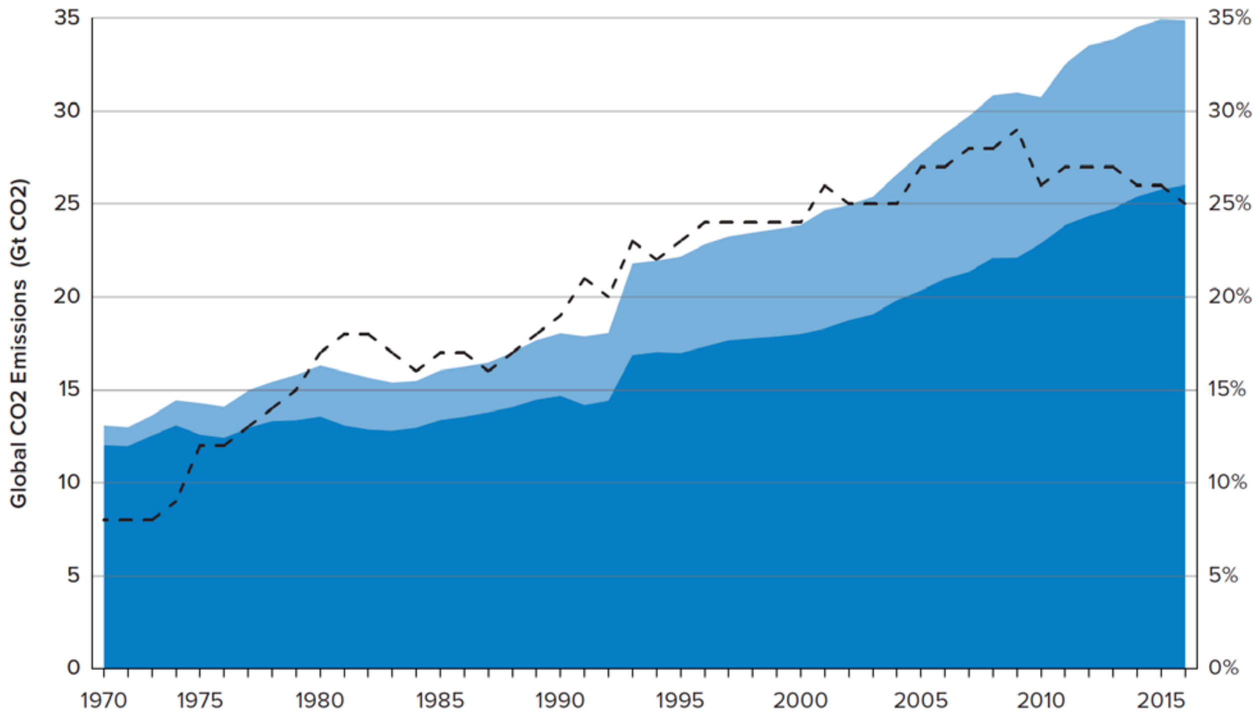

Figure 1. Global CO_2 emissions and proportion embodied in trade (Hasanbeigi et al. 2018)

The embodied carbon in trade is an important feature of global GHG emissions patterns. It represents a growing share of global GHG emissions. This is problematic because embodied carbon flowing in the form of international trade undermines national GHG reduction targets, unless they are set using consumption-based accounting (no countries have set CBA goals to date).

Emissions shifting manifests in several ways: new and existing emitters can relocate; a company can choose a different supplier to fulfill an order; or a decrease in domestic emissions can be more than compensated for by increased imports. The latter can occur when a country shifts from an industrial to an information or service-based economy,which leads to a rise in physical imports to compensate for declining domestic production.The microeconomic decisions underlying emissions shifting are complex,and energy and pollution costs represent only some of the variables that affect businesses' decision-making. These decisions will also vary by type of industry. Regardless of the precise mechanics of emissions shifting (explored by Arto and Dietzenbacher, 2012), the problem is growing.

Overall, developed countries are net importers of embodied carbon. The United States are no exception to this pattern and there are some interesting aspects of this trend observed in the U.S. economy. In the U.S., net import of embodied emissions accelerated rapidly starting in the early 1990s, but declined very sharply with the 2007 global financial crisis. Both direct emissions within the U.S. (territorial emissions) and embodied emissions have roughly plateaued since the financial crisis. It is too soon to say whether this is the beginning of a lasting decarbonization trend or only a momentary lull. Out data only covers until 2015 and doesn't show the trend in the past few years.

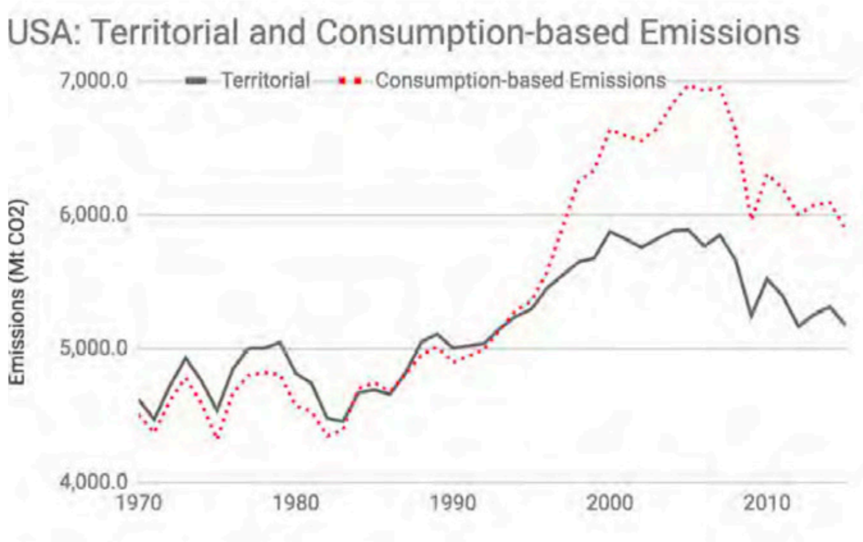

Figure 2. Territorial and consumption-based emissions in the U.S. 1970-2015 (Hasanbeigi et al. 2018)

3 Methodology

To quantify the embodied carbon in U.S. manufacturing and trade, we followed a two-step approach. First, we conducted an input-output analysis to calculate the carbon footprint of 401 aggregate level sectors of the U.S. economy. Second, for a selected number of products, we collected trade (import-export) data and combined that with the computed carbon footprint information of these products to estimate their embodied carbon in import and export for the U.S.

While we conducted the carbon footprint analysis for the entire U.S. economy (all 401 sectors), we only conducted the embodied carbon in trade analysis for a few products within four aggregate level manufacturing sectors, which are as follows:

1. Computer and electronic product manufacturing (NAICS 334),
2. Transport equipment manufacturing (NAICS 336),
3. Machinery manufacturing (NAICS 333),
4. Chemical manufacturing (NAICS 325).

3.1. Analysis of Carbon Footprint of U.S. Manufacturing

The energy and greenhouse gas (GHG) footprint associated with a final demand of one million dollars for the desired sector (or sector in consideration) of the U.S. economy, using data for the year 2012, is calculated using the United States environmentally extended input-output (EEIO) model. The EEIO model methodology outlined by Yang et al. (2017) and researchers at the Green Design Institute at Carnegie Mellon University[1] was followed.

As per the Bureau of Economic Analysis (BEA) input-output accounts, an A matrix represent the direct requirements of the intersectoral relationships. The A matrix depicts the amount of commodity inputs required to produce a dollar of industry output for each sector of the economy.

Next, we consider a vector representing final demand of goods in the economy, Y. The sector in consideration must produce $I \times Y$ units of output to meet this demand (where I is an identity matrix). At the same time $A \times Y$ units of output are to be produced by all first-tier suppliers. The demand of output from the first tier of suppliers creates a demand for output from their direct suppliers (i.e., the second-tier suppliers of the sector in consideration). The second-tier supplier requirements are calculated by further multiplication of the direct requirements matrix by the final demand for first tier suppliers, or $A \times A \times Y$.. The supplier requirements for subsequent tiers are calculated similarly with further multiplication of the direct requirements matrix by the final demand linked with the previous tier. To determine the total output then requires a summation of all of these factors calculated as:

$$\mathbf{X = (I + A + A \times A + A \times A \times A + \ldots)\, Y = (I - A)^{-1}\, Y = LY} \qquad \mathbf{(1)}$$

1 The full methodology can be found in http://www.eiolca.net/Method/index.html

Where,

X is a vector representing total output from all suppliers (both direct and indirect)

A is the direct requirements matrix

L is used in place of $(I - A)^{-1}$ to show the total requirements matrix, also known as the Leontief inverse.

Y is a vector representing final demand

I is the identity matrix

The economic input-output analysis can then be augmented with environmental data. One can determine the total environmental impact associated with a dollar of economic output for each sector of the economy by adding external information to the EIO framework. The resulting matrix which reports environmental impact per dollar output for each sector of the economy is defined as a **R** matrix.

A vector of the total environmental outputs, **B**, can be obtained by multiplying the total economic output (X) by the environmental impact per dollar of output **(R)**:

$$\mathbf{B} = \mathbf{RX} = \mathbf{RLY} \qquad \mathbf{(2)}$$

where
R is a diagonal matrix representing the environmental impact (in terms of energy use or carbon emissions) per dollar output for each sector,

X is a vector representing the total economic output (as obtained from equation (1)),

B is a vector depicting the total carbon emissions or energy use when producing

Y units of final demand, which can also be referred to as a total environmental footprint vector.

In this study, the total footprint (**B**) is estimated for a final demand of 1 million dollars in a sector under consideration, so **Y** in equation (2) is a unit vector. **R** and **L** matrices are also needed for the calculation.

The R matrix values are obtained by deriving the environmental impact values for each sector from the USEEIOv1.1 - Satellite Tables, which are published by U.S. EPA Office of Research and Development (ORD)[2] . Since the Satellite tables report energy use and GHG emissions values for 388 sectors while the BEA input-output tables provide economic data for 405 sectors, some matching work was done in order to obtain energy use and GHG emission values for all 405 sectors. These values are then normalized by each sector's total economic output (as reported by BEA) to obtain an environmental impact per dollar of output value.

The total inputs by commodity required (both directly and indirectly) in order to deliver one million dollar of commodity output to final users (**L** matrix) in 2012 are derived from U.S. Bureau of Economic Analysis (BEA)[3] website . The "After Redefinitions" table was chosen in order to get more accurate carbon and energy footprints (Horowitz and Planting, 2006).

Four sectors could not be modeled because they exist largely as accounting measures: non-comparable imports, used and secondhand goods, rest of world adjustment and scrap (Yang, et al. 2017). Therefore, the energy and GHG footprints are calculated for 401 (rather than 405) sectors.

2 https://catalog.data.gov/dataset/useeiov1-1-satellite-tables
3 https://www.bea.gov/industry/input-output-accounts-data

3.2. Analysis of Embodied Carbon in Trade

After we calculated the carbon footprint of 401 sectors of the U.S. economy through IO analysis, we began our search for trade (import/export) data for products associated with selected sectors. We obtained the 2018 trade data for certain manufacturing products from the U.S. Census Bureau's USA Trade® Online database (U.S. Census Bureau, 2020). The selected products are represented within the following aggregate level sectors: 1. Computer and electronic product manufacturing (NAICS 334), Transport equipment manufacturing (NAICS 336), Machinery manufacturing (NAICS 333), Chemical manufacturing (NAICS 325).

On the basis of the carbon footprint of each product manufactured in the U.S. from our IO analysis and the export data of the product (in million US$), we can calculate the embodied carbon in the U.S. export of the product using the following equation:
Embodied carbon in U.S. export of product X (tCO_2 -eq) = Carbon footprint of product X (tCO_2-eq/ million US$) × Export of product X (million US$)

We calculated the embodied carbon in U.S. export of selected products for all the countries in the world to which U.S. exported those products in 2018. It should be noted that some portion of the products that countries import from the U.S. might be exported to a third country. We do not have the information of final destination of products and we did our analysis based on countries to which U.S. exported the product and reported as such in the U.S. trade data.

To calculate the embodied carbon in the U.S. import of products, however, we took a different approach. Due to the infeasibility associated with carrying out a comprehensive carbon footprint analysis for products imported by the U.S. from different regions of the world, we estimated the carbon footprint of products produced in other countries based on the carbon footprint of products produced in the U.S. To do this estimation we utilized the following two-step analysis.

First, we analyzed the power sector GHG contribution to the carbon footprint. From our U.S. IO analysis, we got each sector's contribution to the total carbon footprint for each product, including power sector's GHG contribution. We obtained the CO_2 emissions factor for the power grid for the U.S. and the top twenty countries from which U.S. imports a given product (U.S. DOE/EIA 2019, IGES 2019, Moro and Lonza 2018) (Figure 3). Based on the ratio of grid emissions factor between the U.S. and its twenty major trading partners, we adjusted the power sector GHG contribution to the carbon footprint that we had calculated for the U.S., to calibrate the U.S. carbon footprint calculation for the targeted countries.

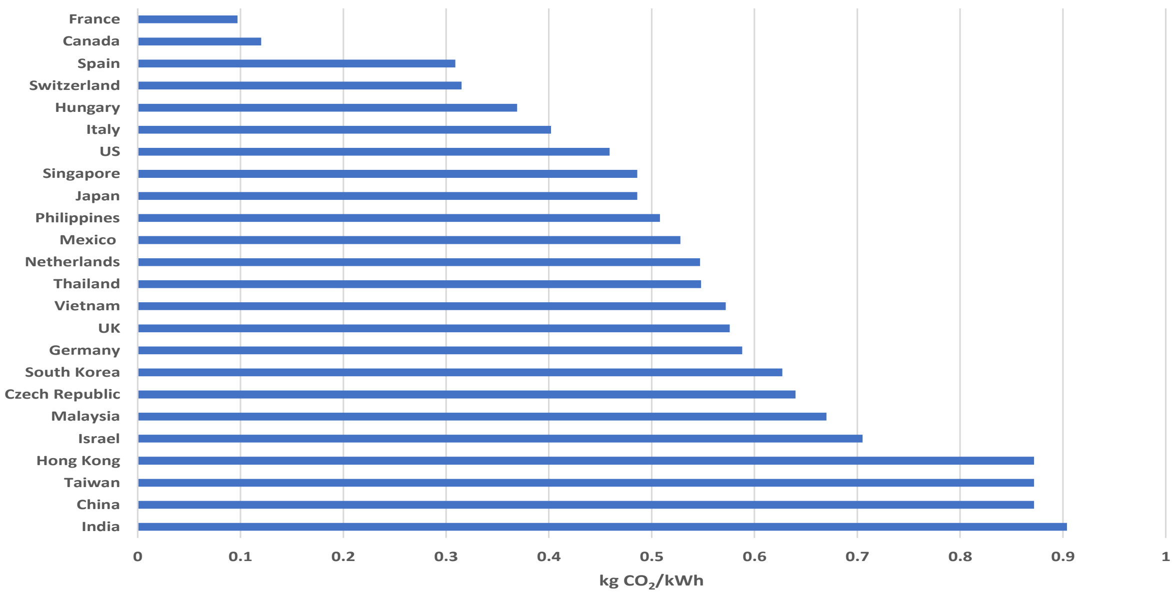

Figure 3. Electricity grid CO_2 emissions factor in selected countries in 2017 (kg CO_2/kWh)

Second, we calculated a weighted average CO_2 emissions factor of fuels (non-electricity) used in industry (kg CO_2/GJ) in the U.S. and top twenty countries from which U.S. imports a given product based on IEA (2019) data (Figure 4). On the basis of the ratio of weighted average CO_2 emissions factor of fuels used in industry in the U.S. and its other twenty major trading partners, we adjusted the non-power sector GHG contribution to the carbon footprint that we had calculated for the U.S., to calibrate the U.S. carbon footprint calculation for the targeted countries. This calibration was done because different fuel types are used in industries across different countries which results in varying emissions factors. For example, while a significant proportion of the fuel used by industries in the U.S. is natural gas, which is abundant in the U.S. at low prices, a large proportion of fuel used by industries in China is coal, which has a high carbon content per unit of energy (CO_2/GJ).

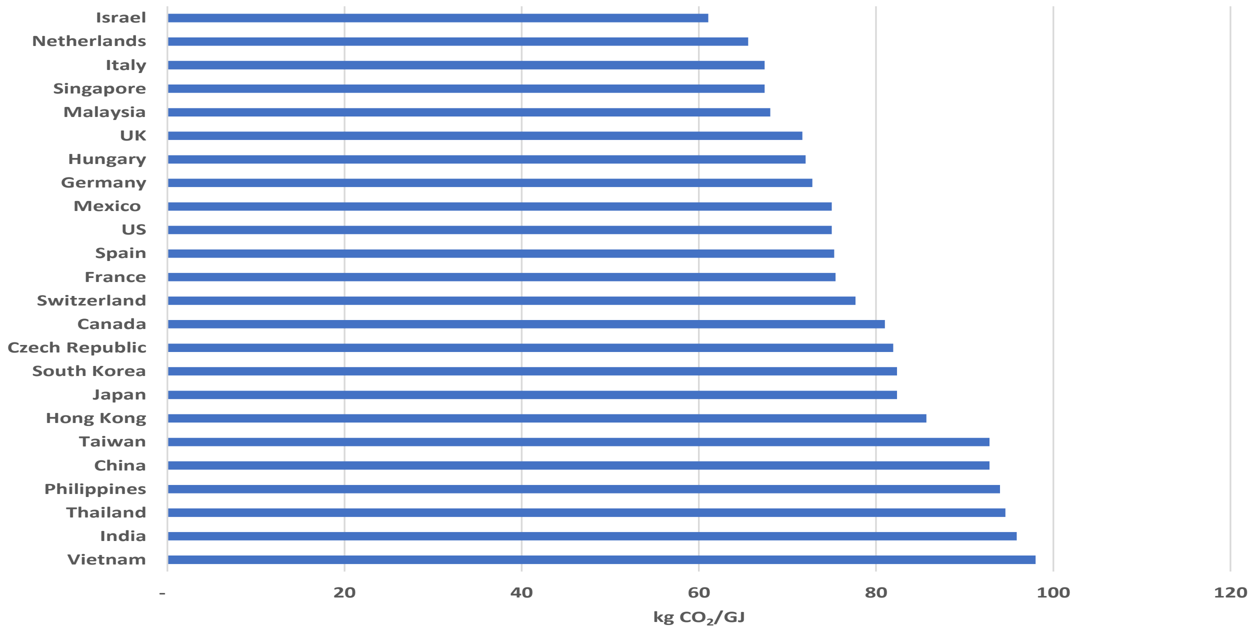

Figure 4. Weighted Average CO_2 emissions factor of fuels used in industry in selected countries in 2017 (kg CO_2/GJ)

The aforementioned analysis allowed us to estimate the carbon footprint of products in many different countries based on the IO analysis we had conducted for the U.S. While this added a certain level of uncertainty to the results, we believe that for the purpose of policy making, such levels of uncertainty are acceptable.

On the basis of the estimated carbon footprint of each product imported to the U.S. from each of the top twenty countries based on the import of the product, we can calculate the embodied carbon in the U.S. import of the product using the following equation:

Embodied carbon in U.S. import of product X from country Y (tCO_2-eq) = Carbon footprint of product X in country Y (tCO_2-eq/million US$) × Import of product X from country Y(million US$)

We calculated the embodied carbon in U.S. import of selected products for top twenty countries from which U.S. imported those products in 2018.

After doing these analyses, we identified top international flow of embodied carbon in U.S. trade (import/export) for the selected products. These results are presented in the next section.

4 Embodied carbon in the U.S. trade of selected products

As mentioned above, we only conducted detailed embodied carbon in trade analysis for a few products within select aggregate level U.S. manufacturing sectors, i.e. computer and electronic product manufacturing, transport equipment manufacturing, machinery manufacturing, and chemical manufacturing. The selected products within these manufacturing sectors ranked high in terms of magnitude of embodied carbon in import and/or export.

4.1. Embodied Carbon in the U.S. Trade of Selected Computer and Electronic Products

In this section we present the results of our analysis for embodied carbon in the U.S. trade of selected products within computer and electronic products sector (NAICS 334).

Figure 5 shows the top flows of CO_2 emissions embodied in the U.S. import and export of electronic computers (NAICS 334111) in 2018. As can be seen, the embodied CO_2 emissions in U.S. imports of electronic computers from China is by far the largest, accounting for over 65% of total embodied CO_2 femissions in U.S. import of these products. The embodied CO_2 emissions in U.S. export of electronic computers are the largest for Canada and Mexico, accounting for around 30% and 10% of total embodied CO_2 emissions in U.S. export of these products, respectively.

Overall, the U.S. is a net importer of embodied CO_2 emissions in electronic computers with total embodied emissions in U.S. imports (over 8.8 million tonne (Mt) CO_2) exceeding the embodied emissions in U.S. export (around 1.2 Mt CO_2) of these products by greater than 7 times. The top 10 countries that the U.S. exports electronic computers to and the top 6 countries that the U.S. imports these products from account for 70% and 98% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

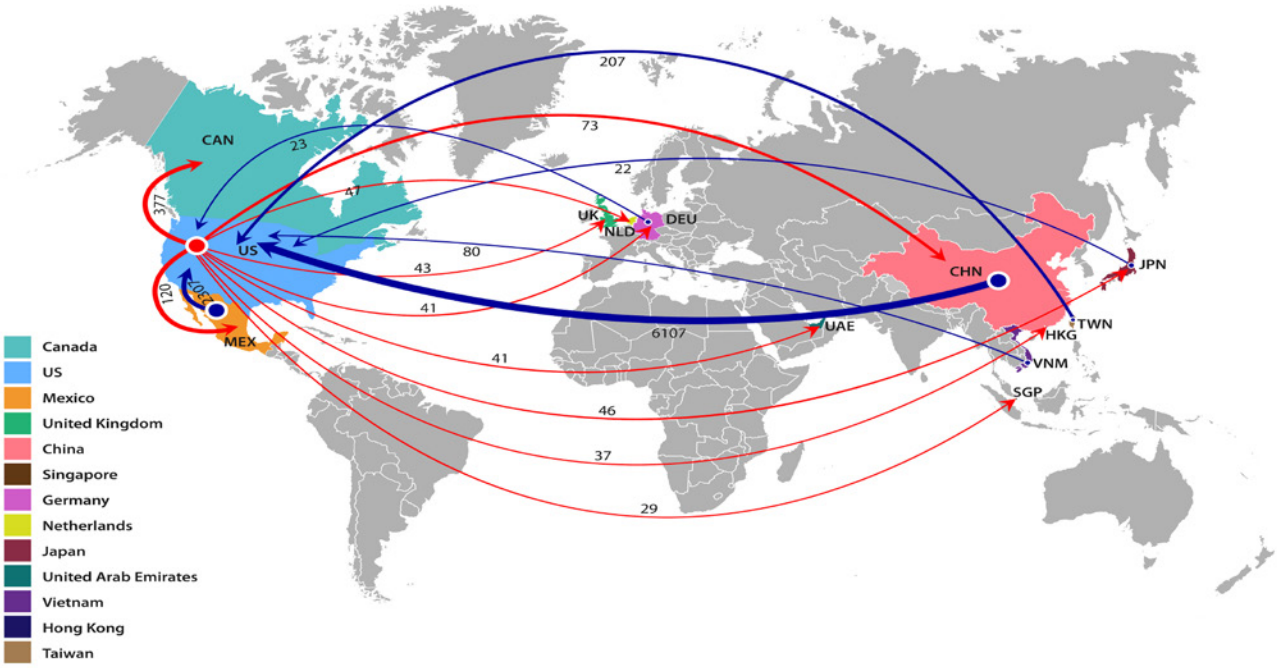

Figure 5. Top flows of CO_2 emissions embodied in the U.S. import and export of Electronic Computers (NAICS 334111) in 2018 (kt CO_2)

Figure 6 shows the top flows of CO_2 emissions embodied in the U.S. import and export of computer storage devices (NAICS 334112) in 2018. The embodied CO_2 emissions in U.S. imports of computer storage devices from Thailand and China accounted for around 48% and 18% of total embodied CO_2 emissions in U.S. import of these products, respectively. The embodied CO_2 emissions in U.S. export of computer storage devices to Mexico and Canada are the largest, accounting for around 53% and 10% of total embodied CO_2 emissions in U.S. export of these products.

The U.S. is a net importer of embodied CO_2 emissions in computer storage devices with embodied emissions in U.S. imports (around 2 Mt CO_2) almost twice that of the embodied emissions in U.S. export (around 1 Mt CO_2) of these products. The top 10 countries that the U.S. exports computer storage devices to and the top 6 countries that the U.S. imports these products from account for 80% and 95% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

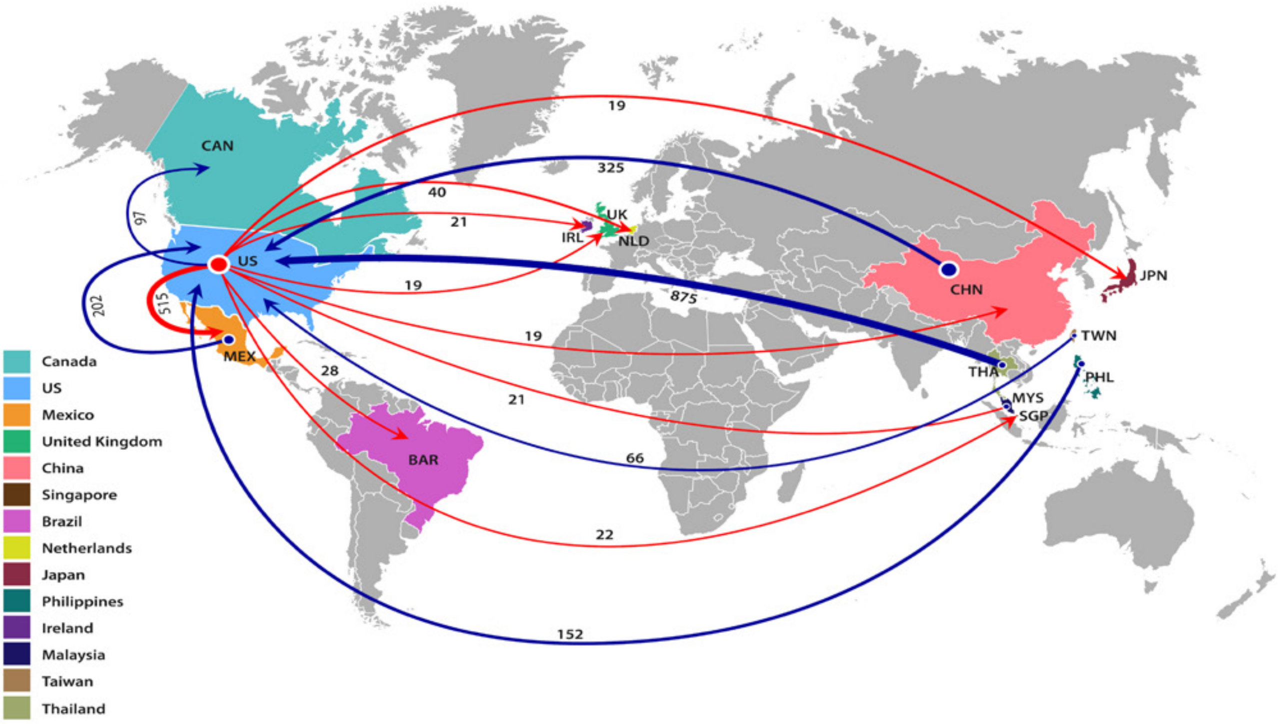

Figure 6. Top flows of CO_2 emissions embodied in the U.S. import and export of Computer Storage Devices (NAICS 334112) in 2018 (kt CO_2)

Figure 7 shows the top flows of CO_2 emissions embodied in the U.S. import and export of semiconductors (NAICS 334413) in 2018.The embodied CO_2 emissions in U.S. imports of semiconductors from Malaysia and China accounted for around 38% and 15% of total embodied CO_2 emissions in U.S. import of these products, respectively. The embodied CO_2 emissions in U.S. export of semiconductors to Mexico and China are the largest, accounting for around 18% and 15% of total embodied CO_2 emissions in U.S. export of these products.

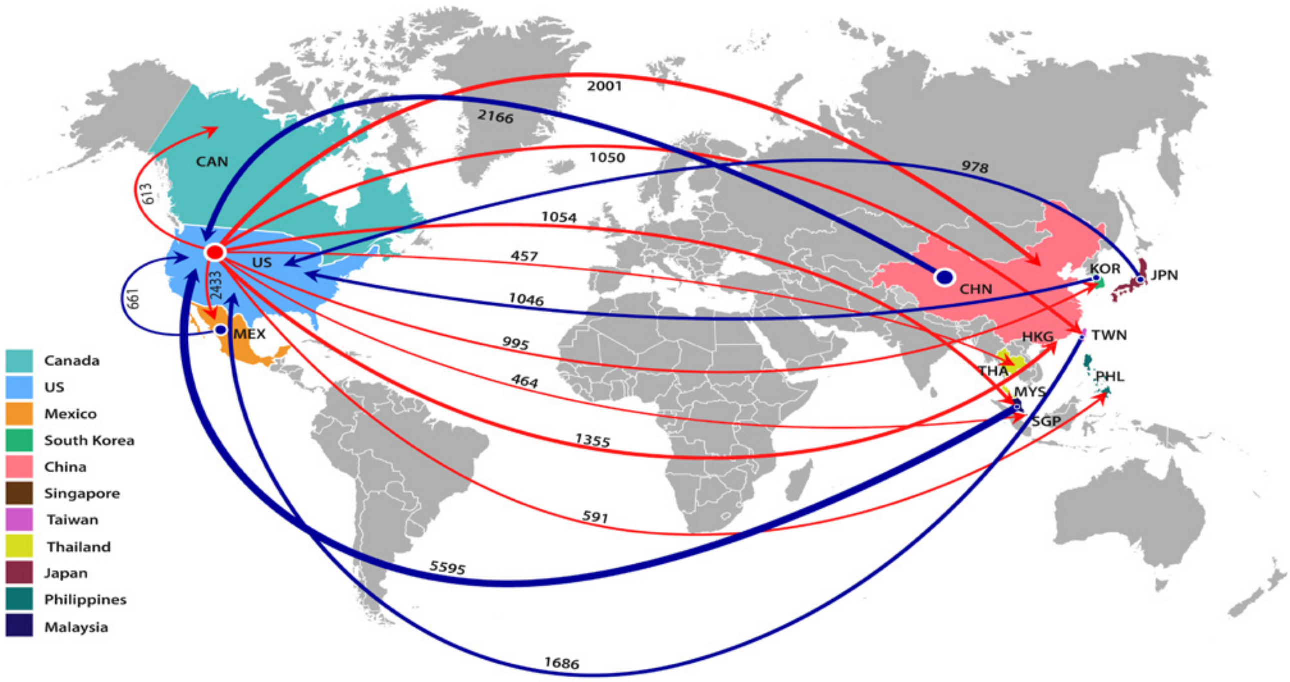

Figure 7. Top flows of CO_2 emissions embodied in the U.S. import and export of Semiconductors (NAICS 334413) in 2018 (kt CO_2)

4.2. Embodied Carbon in the U.S. Trade of Selected Transport Equipment Products

In this section we present the results of our analysis for embodied carbon in the U.S. trade of selected products within the transport equipment sector (NAICS 336).

The top flows of CO_2 emissions embodied in the U.S. import and export of autos and light duty motor vehicles (NAICS 336111) in 2018 are shown in Figure 8. Japan, Mexico, and Canada accounted for about 66% of the total embodied CO_2 emissions in U.S. import of these products in 2018. The embodied CO_2 emissions in U.S. export of autos and light duty motor vehicles (NAICS 336111) to Canada and China are the largest, accounting for around 33% and 14% of total embodiedCO_2 emissions in U.S. export of these products.

The U.S. is a net importer of embodied CO_2 emissions in autos and light duty motor vehicles with embodied emissions in U.S. imports (over 76 Mt CO_2) about 3.8 times higher than the embodied emissions in U.S. export (around 20 Mt CO_2) of these products. The top 10 countries that the U.S. exports autos and light duty motor vehicles to and the top 6 countries that the U.S. imports these products from account for 84% and 94% of total embodied CO_2 emissions in the US export and import of these products, respectively.

The top flows of CO_2 emissions embodied in the U.S. import and export of light trucks and utility vehicles (NAICS 336112) in 2018 are shown in Figure 9. Mexico alone accounted for about 90% of the total embodied CO_2 emissions in U.S. import of these products. The embodied CO_2 emissions in U.S. export of light trucks and utility vehicles (NAICS 336112) to Canada is the largest, accounting for around 84% of total embodied CO_2 emissions in U.S. export of these products.

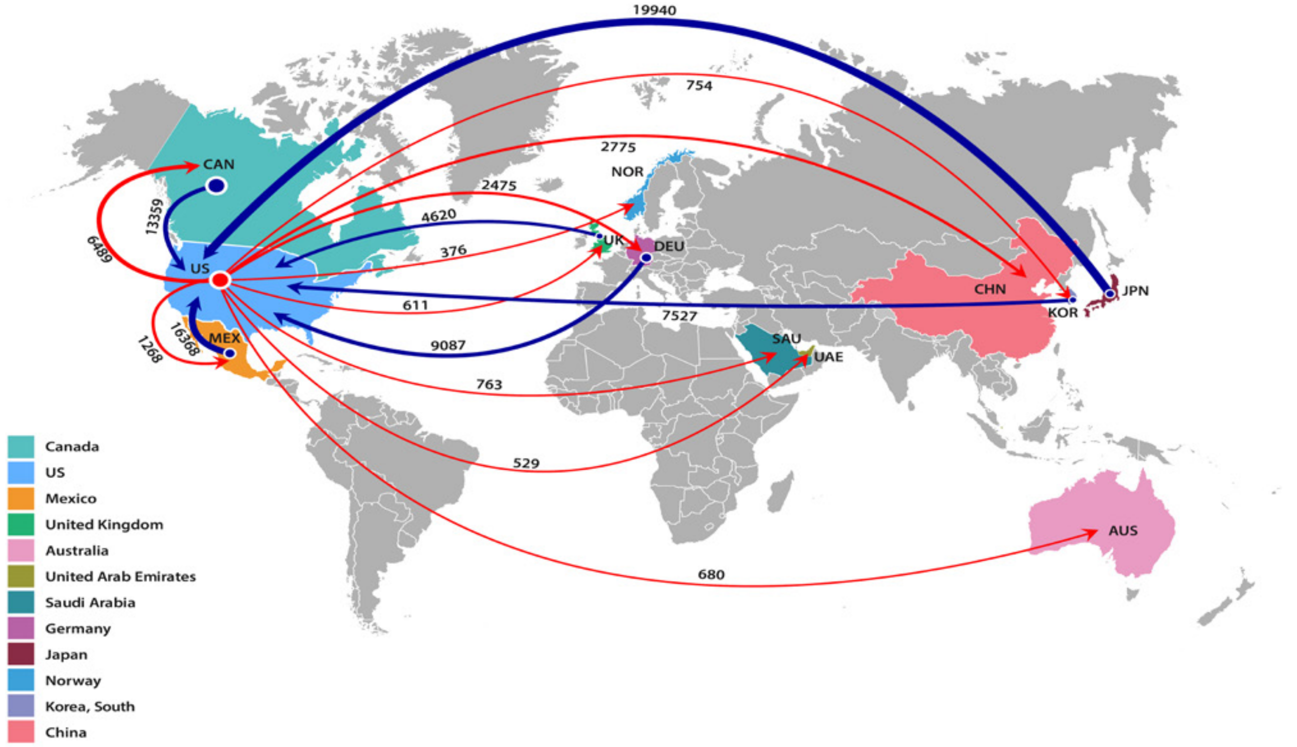

Figure 8. Top flows of CO_2 emissions embodied in the U.S. import and export of autos and light duty motor vehicles (NAICS 336111) in 2018 (kt CO_2)

The U.S. is a net importer of embodied CO_2 emissions for light trucks and utility vehicles with embodied emissions in U.S. import (around 11 Mt CO_2) over twice the embodied emissions in U.S. export (around 5 Mt CO_2) of these products. The top 10 countries that the U.S. exports light trucks and utility vehicles to and the top 6 countries that the U.S. imports these products from account for over 97% and 99% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

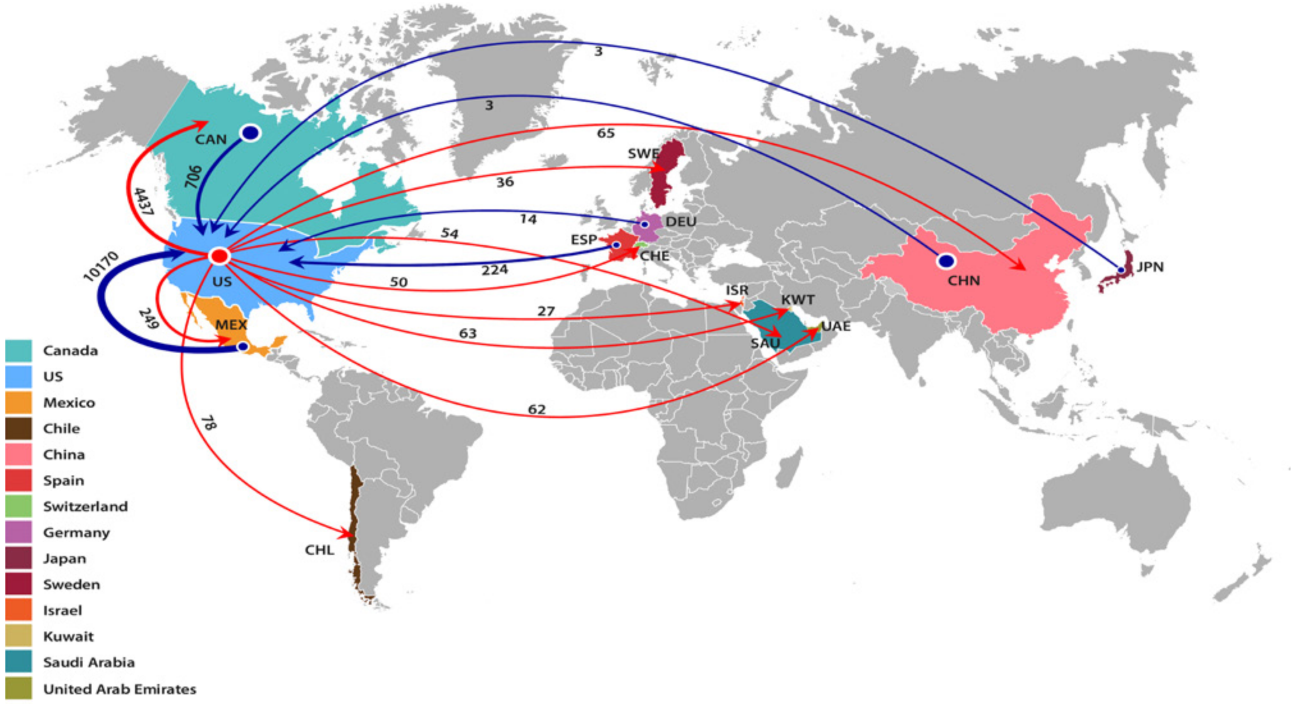

Figure 9. Top flows of CO_2 emissions embodied in the U.S. import and export of light truck and utility vehicle (NAICS 336112) in 2018 (kt CO_2)

4.3. Embodied Carbon in the U.S. Trade of Selected Machinery Products

In this section we present the results of our analysis for embodied carbon in the U.S. trade of selected products within the machinery products sector (NAICS 333).

Figure 10 shows the top flows of CO_2 emissions embodied in the U.S. import and export of construction machinery (NAICS 333120) in 2018. The embodied CO_2 emissions in U.S. imports of construction machinery from Japan, Mexico, and China accounted for around 25%, 15%, and 14% of total embodied CO_2 emissions in U.S. import of these products, respectively. The embodied CO_2 emissions in U.S. export of construction machinery to Canada are the largest, accounting for around 45% of total embodied CO_2 emissions in the U.S. export of these products.

The U.S. is a net importer of embodied CO_2 emissions in construction machinery with embodied emissions in U.S. imports (around 9.5 Mt CO_2) exceeding the embodied emissions in U.S. exports (around 7 Mt CO_2) of these products by about 30%. The top 10 countries that the U.S. exports construction machinery to and the top 6 countries that the U.S. imports these products from account for 77% and 82% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

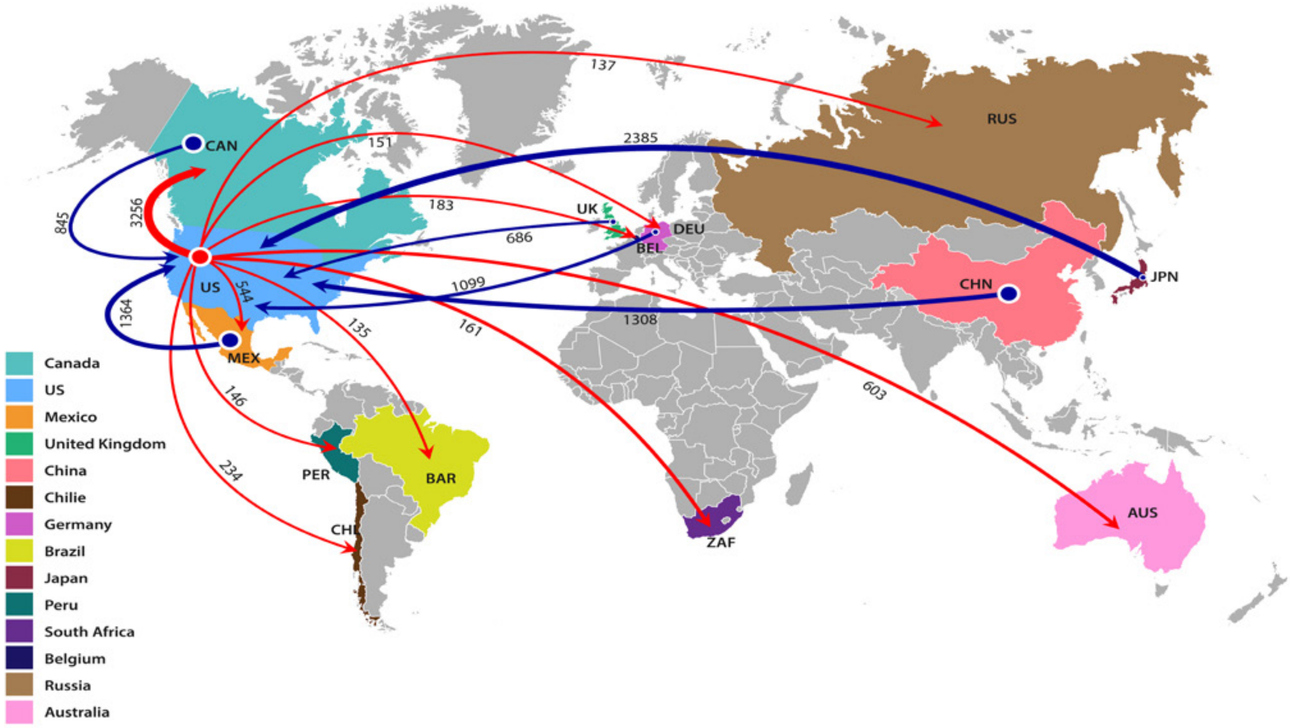

Figure 10. Top flows of CO_2 emissions embodied in the U.S. import and export of construction machinery (NAICS 333120) in 2018 (kt CO_2)

The top flows of CO_2 emissions embodied in the U.S. import and export of semiconductors machinery (NAICS 333242) in 2018 is shown in Figure 11. The embodied CO_2 emissions in U.S. imports of semiconductors machinery from China and Japan accounted for around 41% and 20% of total embodied CO_2 emissions in U.S. import of these products, respectively. The embodied CO_2 emissions in U.S. export of semiconductors machinery to South Korea and China are the largest, accounting for around 25% and 20% of total embodied CO_2 emissions in U.S. export of these products.

The U.S. is a net exporter of embodied CO_2 emissions in semiconductors machinery with embodied emissions in U.S. export (around 5.6 Mt CO_2) about 10% higher than the embodied emissions in U.S. import (around 5.1 Mt CO_2) of these products. The top 10 countries that the U.S. exports semiconductors machinery to and the top 6 countries that the U.S. imports these products from account for 95% and 87% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

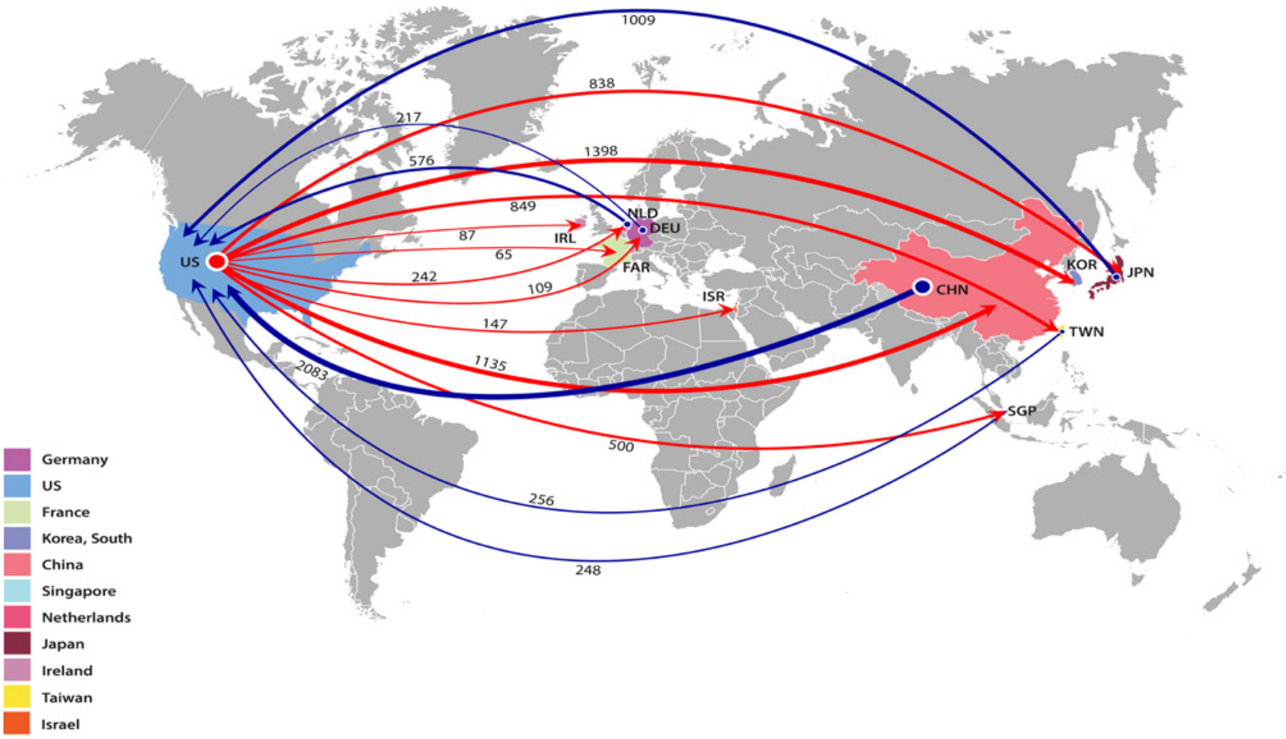

Figure 11. Top flows of CO_2 emissions embodied in the U.S. import and export of semiconductors machinery (NAICS 333242) in 2018 (kt CO_2)

4.4. Embodied Carbon in the U.S. Trade of Selected Chemical Products

In this section we present the results of our analysis for embodied carbon in the U.S. trade of selected products within chemical products sector (NAICS 325).

Figure 12 shows the top flows of CO_2 emissions embodied in the U.S. import and export of pharmaceutical preparations products (NAICS 325412) in 2018. The embodied CO_2 emissions in U.S. imports of pharmaceutical preparations products from Ireland, Switzerland, and India accounted for around half of total embodied CO_2 emissions in U.S. import of these products. The embodied CO_2 emissions in U.S. export of pharmaceutical preparations products to UK and Canada are the largest, accounting for around 11% and 9% of total embodied CO_2 emissions in U.S. export of these products.

The U.S. is a net importer of embodied CO_2 emissions in pharmaceutical preparations products with embodied emissions in U.S. import (around 20.6 Mt CO_2) about three times higher than the embodied emissions in U.S. export (around 6.7 Mt CO_2) of these products. The top 10 countries that the U.S. exports pharmaceutical preparations products to and the top 6 countries that the U.S. imports these products from account for 72% and 70% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

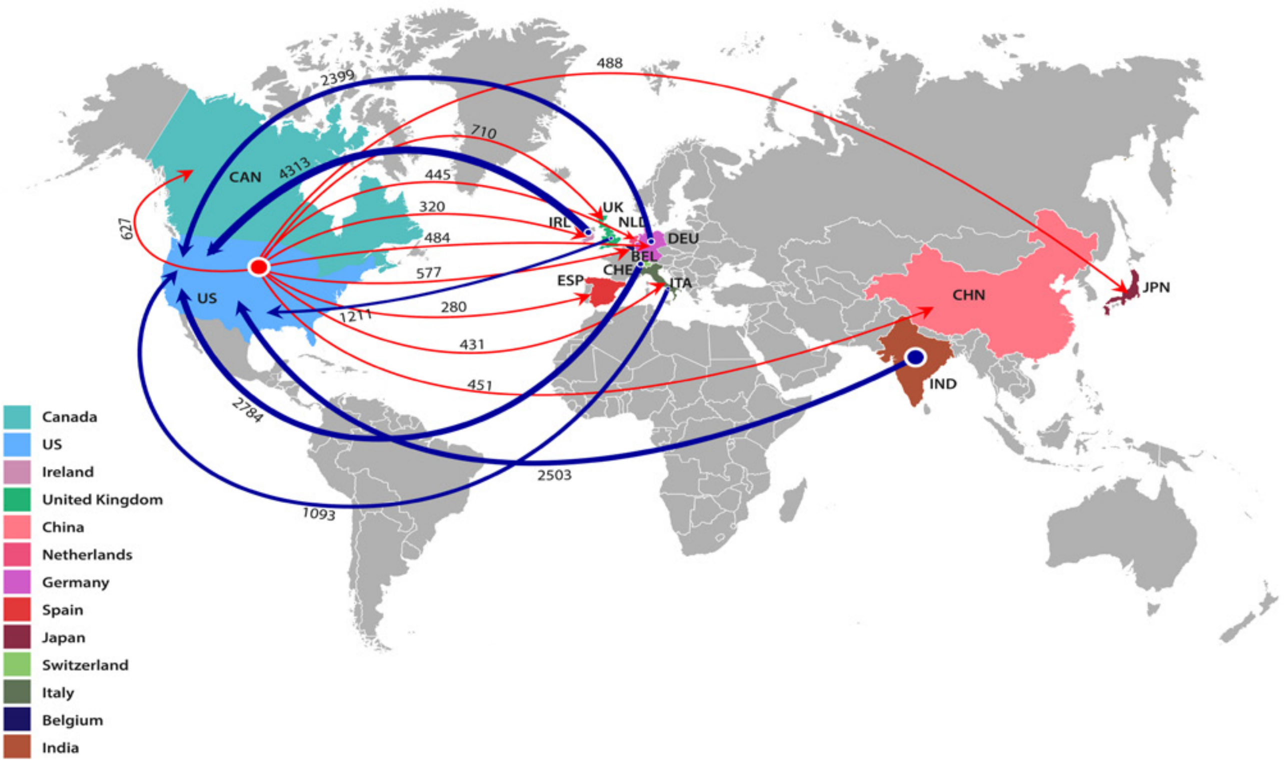

Figure 12. Top flows of CO_2 emissions embodied in the U.S. import and export of pharmaceutical preparations products (NAICS 325412) in 2018 (kt CO_2)

The top flows of CO_2 emissions embodied in the U.S. import and export of plastics materials and resins (NAICS 325211) in 2018 are shown in Figure 13. The embodied CO_2 emissions in U.S. imports of plastics materials and resins from Canada and Germany accounted for around 34% and 10% of total embodied CO_2 emissions in U.S. import of these products, respectively. The embodied CO_2 emissions in U.S. export of plastics materials and resins to Mexico and Canada are the largest, accounting for around 24% and 18% of total embodied CO_2 emissions in US export of these products.

The U.S. is a net exporter of embodied CO_2 emissions in plastics materials and resins with embodied emissions in U.S. exports (around 40 Mt CO_2) exceeding the embodied emissions in U.S. imports (around 18 Mt CO_2) of these products by more than two times. The top 10 countries that the U.S. exports plastics materials and resins to and the top 6 countries that the U.S. imports these products from account for 74% and 79% of total embodied CO_2 emissions in the U.S. export and import of these products, respectively.

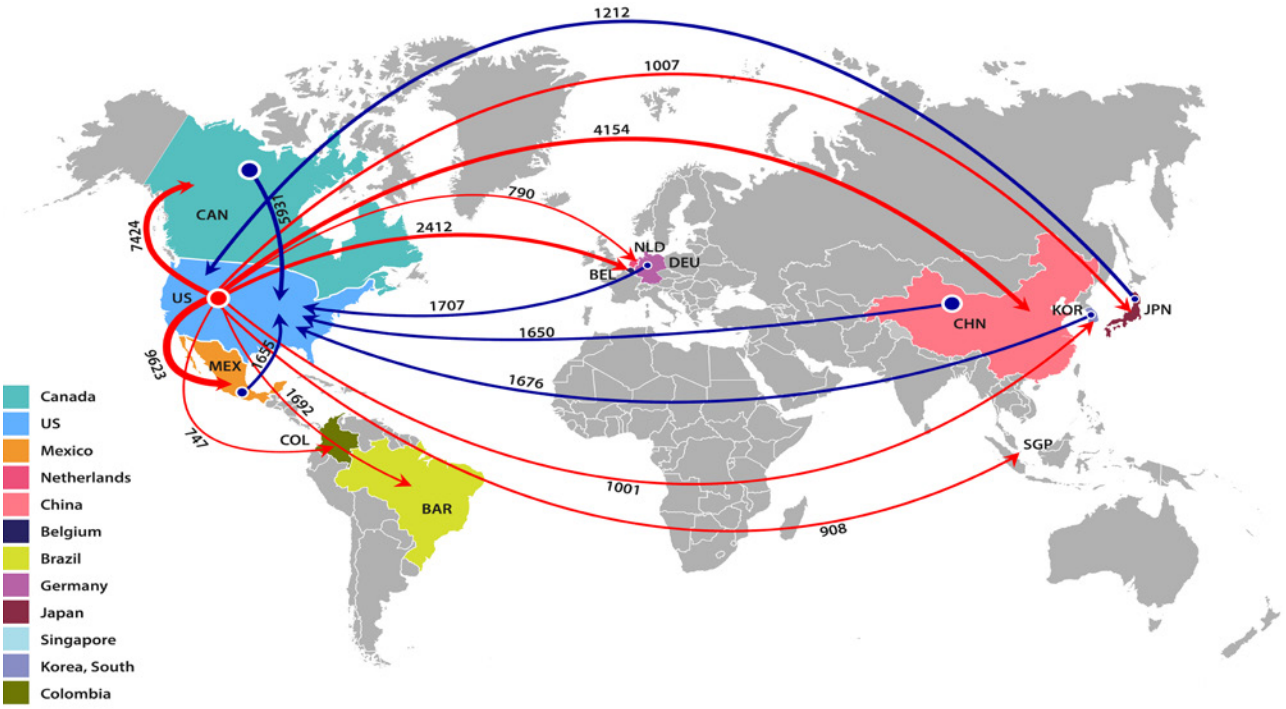

Figure 13. Top flows of CO_2 emissions embodied in the U.S. import and export of plastics materials and resins (NAICS 325211) in 2018 (kt CO_2)

5 Conclusions and policy recommendations

This study aims to use the latest available data to quantify the carbon footprint for over 400 aggregate level sectors of the U.S. economy. In addition, the study aims to estimate the embodied carbon in certain traded manufacturing products in the U.S. The results of our analysis for a few selected subsectors/products are presented in this report.

The results of our analysis for the selected products show the embodied carbon in trade for each product by country and also show the rankings of countries in terms of top importers and exporters of embodied carbon in trade with the U.S. Our results show that in the majority of cases, the U.S. is a net importer of embodied carbon in trade. It should be noted that the results of this study are estimates based on the methodology explained in this report. Using country-specific IO tables and products carbon footprint for the U.S. trading partners could increase the accuracy of the estimated embodied carbon in U.S. imports. This was outside the scope of this study and can be a subject of future studies.

Consumption-based emissions accounting can inform policymaking that aims to address embodied carbon in trade. Many of these policy tools are not entirely new, but in order to effectively address embodied carbon they may require a specific focus on these emissions, thereby building on or expanding existing or emerging policies. We examine applications of embodied emissions accounting by dividing policy interventions along broad phases of the supply chain: production, the intermediate supply chain, and consumption. Policies listed under production include those that regulate within national borders, while intermediate products may be traded across borders. Consumption policies address consumption by households, government, businesses, and other actors. A selection of policies is summarized in Table 1.

Table 1. CBA Policy applications by product lifecycle phase (Hasanbeigi et al. 2018)

Lifecycle Phase		
Production	**Intermediate Supply Chain**	**Consumption**
Point-source and industry-level regulations	Border tax adjustments	Policies targeting household behaviors
Product location at sale	Technology transfer policies (offsets)	Government and business procurement
National emissions targets	Best Available Technology standards	Retailer certifications and product choice
New metrics for emissions accounting	Voluntary agreements by trade associations	Information, ranking, and award campaigns

Production Policies and Applications

Production policies aim to address mitigation within national borders. Mitigation policies at the national level and below should be carefully designed to minimize leakage (either through shifting domestic production to carbon-intensive imports or through long-term relocation of production to unregulated regions outside national borders). Carbon pricing can be designed to reduce leakage. Under an emissions trading system (ETS), there is a tradeoff between providing industries with free emissions allowances in order to prevent carbon leakage, and achieving the emissions reductions goals of the ETS. Other studies recommend adjusting consumption-based accounting for carbon pricing to better incorporate trade balance and specialization (Jakob and Marschinski 2013). The report by Becque et al. (2018) provides greater elaboration on potential key policy actions.

National emissions reduction policies can be guided by consumption-based accounting, including the inventories in the studies covered previously as well as new metrics such as technology-adjusted consumption-based accounting (TCBA), which adjusts for the carbon intensity of export sectors around the world (Kander et al. 2015). Simply increasing consumption-based accounting can also help countries determine their role in the carbon loophole, as well as identifying key sectors and geographies that drive carbon leakage (Minx et al. 2009). At present, fuel and GHG suppliers in California and some parts of the United States as well as several companies in France are the only firms subject to mandatory reporting of indirect and embodied emissions. A number of countries provide voluntary, government-initiated reporting on their embodied emissions, mostly through Multi-Regional Input-Output (MRIO) analysis, such as the UK, France, Sweden, and Denmark. Mandatory sustainability reporting for businesses and countries can help increase awareness and use of CBA approaches to GHG management.

Intermediate Supply Chain Policies and Applications

Intermediate supply chain policies aim to address products that are traded across borders. CBA can be used to close the carbon loophole between developed and developing countries through financial transfers to developing countries for emissions reduction projects (a.k.a. offsets). Some studies have shown that offsets are a cost-effective mechanism for reducing carbon leakage (Springmann 2014). There are many offset programs around the world, such as the Clean Development Mechanism and REDD+.

Border tax adjustments (BTAs) are another commonly discussed policy for closing the carbon loophole at national borders. BTAs would essentially tax imported products based on their carbon intensity. To date, no country has implemented BTAs (possibly out of concern for violation of WTO trade rules), but the EU has discussed taxing import of energy-intensive goods as part of the emissions trading system reform, and carbon BTAs were considered in the past. Given that BTAs can put exporting countries at a disadvantage, some studies have recommended that BTAs be combined with revenue redistribution to the exporting countries and technology transfer deals (Steininger et al. 2014).

Another main example of interventions in the supply chain is voluntary sustainable trade programs, which mostly address agricultural and forestry products whose production has been associated with deforestation (and therefore carbon emissions) in developing countries. Examples include commodity-specific roundtables, such as the Roundtable on Sustainable Palm Oil or the Roundtable on Sustainable Beef, which engage industry stakeholders and provide standards for production. There are also numerous certification schemes for products, such as the Fair-Trade label.

Consumption Policies and Applications

Consumption policies aim to address end use of products by households,government,businesses, and other actors. Many countries have policies and/or programs in place that indirectly address embodied carbon of imported goods by reducing consumption of carbon-intensive products. Sustainable procurement programs set standards for goods consumed by a given institution, often government agencies or individual businesses. These procurement guidelines can be voluntary or mandatory. For example, in Denmark, the central government is required to procure sustainable timber for their buildings, furniture, and paper products. There is also a voluntary Green Public Procurement initiative organized by the European Commission for governments in the EU to implement as they desire. The Buy Clean Act in California requires state agencies to consider the embodied emissions in steel, glass, and other building materials when contracting for state-funded infrastructure projects. While non-mandatory, many behavioral policies and labeling campaigns target household consumers, encouraging them to make environmentally responsible purchasing and consumption choices.

Going forward, countries should increase awareness of the carbon loophole and the need to address these emissions. Following acknowledgment, policymakers can adopt a consumption-based accounting framework to begin to annually measure and report their embodied emissions footprint. Finally, countries can adopt policies that target production, the intermediate supply chain, and consumption as discussed above.

Unless consumption-based accounting is used, countries may continue to outsource their emissions to meet their Paris Agreement targets, as observed previously with the Kyoto Protocol. Countries have reported reductions that exceeded their Kyoto targets, however, the changes in emissions embodied in imports are comparable to or larger than changes in domestic emissions. Traded emissions undermined emissions reductions in the Kyoto Protocol, and threaten to continue to do so for the Paris Agreement. New climate policies such as California's Buy Clean act, EU's proposed border carbon tax adjustment and other green public procurement policies around the world (Hasanbeigi et al. 2019), as well as efforts in the private sector can help to address the embodied carbon in traded products.

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